INTRODUCTION
The gait of a unilateral lower limb amputee is asymmetrical [1], which applies increased stress on the intact leg [2] and can cause long-term complications. The most common complications, due to this altered load distribution and gait asymmetry for people who have lived with an amputation for long time are back and/or intact limb pain [3,4], osteoarthritis in the intact limb [2,3], osteopenia/osteoporosis in the residual limb [2], and other musculoskeletal problems [4]. For the above-knee amputee (AKA), the prosthetic knee joint is one of the most critical components of the prosthesis because it influences all of these outcomes. Prosthetic knees can be classified into those that use mechanical control of the knee joint (non-microprocessor knee, NMPK) and those that use microprocessor control (MPK). The purpose of this study was to compare the gait asymmetry of active transfemoral amputees while using a NMPK compared to a MPK. We hypothesized that the patient would have improved gait symmetry when wearing a MPK.

METHODS
The study cohort consisted of 15 subjects (12 men and 3 women; mean age 42 ± 9 years) who had a unilateral above-knee amputation due to trauma (7), cancer (6), peripheral vascular disease (1), or congenital factors (1). All subjects were long-term prosthesis users (20 ± 10 years). They were tested with a mechanical fluid-controlled knee prosthesis (11 Mauch SNS, 2 CaTech, 1 Black Max, 1 Century 2000) and retested with a microprocessor-controlled knee joint (Otto Bock C-Leg) after an acclimation period (18 ± 8 weeks). Informed consent was obtained prior to enrollment into the study. Inclusion criteria to participate in this study were unilateral transfemoral amputation, age >18 years, at least two years experience using a prosthesis, Medicare Functional Classification Level 3 or 4, utilization of a microprocessor- controlled knee prosthesis (11 Mauch SNS, 2 CaTech, 1 Black Max, 1 Century 2000) and retested with a microprocessor- controlled knee joint (Otto Bock C-Leg) after an acclimation period (18 ± 8 weeks). Informed consent was obtained prior to enrollment into the study. Inclusion criteria to participate in this study were unilateral transfemoral amputation, age >18 years, at least two years experience using a prosthesis, Medicare Functional Classification Level 3 or 4, utilization of a passive mechanical prosthetic knee, no significant fluctuation in stump volume within the last 6 months, no other neuromuscular problems or a partial amputation of the contralateral limb, no acute illness or chronic illness, assistive aids for ambulation, and no dialysis. No restrictions were placed on gender or race. Prosthetic alignment was quantified using the Otto Bock Laser Assisted Static Alignment Reference (LASAR) system [5].

Kinematic parameters were acquired with a computerized video motion analysis system utilizing ten infrared cameras (EvaRT 4.0, Motion Analysis Corporation, Santa Rosa, CA). Ground reaction forces were measured using four force plates (two AMTI and two Kistler) embedded in a 10m walkway synchronized to the video system. Kinematic and ground reaction force data were collected at 120 and 360 Hz, respectively. The 3D marker coordinates and force plate data were used as input to a commercial software program (OrthoTrak 5.0, Motion Analysis Corp., Santa Rosa, CA) to calculate the 3D joint kinematics and kinetics.

A symmetry index was calculated during the stance and swing phase of the gait cycle for each subject [6]. The method utilized is similar to the method proposed by Crenshaw and Richards [7] with several modifications. The symmetry index was calculated as the ratio between the variance about the eigenvector and the variance along the eigenvector. The obtained value was subtracted from 1.0 and the sign associated with the slope of the eigenvector was assigned. A value of +1 indicated perfect symmetry between the two waveforms, while a value of -1 indicated perfect asymmetry. A two-way, repeated measure Analysis of Variance (2 gait phases × 2 knees) was used for determining whether subjects differed in their gait symmetry when wearing the different prosthetic knees. Statistical significance was set at p = 0.05.

RESULTS AND DISCUSSION
All subjects completed the full protocol with each type of knee prosthesis. The key differences were in the sagittal plane. There was no significant difference in hip kinematic symmetry between the two knee prostheses (Figure 1). At the knee joint, there was stance phase asymmetry that in most cases depended on differences in knee extension. This behavior was more prominent in the case of the NMPK with respect to MPK, but the difference was not statistically significant. In the swing phase, most of the subjects had symmetrical behavior. At the ankle joint, asymmetry in the stance phase was not a common behavior; while in the swing phase the symmetry index was close to -1, thus indicating almost perfect asymmetry. This was primarily due to the lack of plantarflexion at the prosthetic foot. No significant differences were found in the symmetry indexes for ankle kinematics between NMPK and MPK, however a trend was evident (p=0.07).
The joint moments exhibited a symmetrical behavior for all joints (symmetry index close to 1) except for the knee in the stance phase (Figure 2). The statistical analysis revealed a significant difference between NMPK and MPK in both phases of gait at all joint levels (p<0.05). In particular, all subjects demonstrated significant improvement in gait symmetry at the knee after receiving the MPK (p<0.0001). However, both prosthetic knee moments remained significantly decreased compared to the contralateral limb and non-amputee controls. The symmetry indices of the sagittal kinematics and kinetics of the control subjects were equal at 0.99 for both gait phases.

![Figure 2. Symmetry index for kinetics in the sagittal plane for three joints (hip, knee, ankle) and two different prostheses. There was a significant difference of the symmetry index between the MPK and NMPK.](image)

The results demonstrated a statistically significant improvement in gait symmetry at the knee for the sagittal plane moments when using a MPK. Segal [8] reported similarly that the stance knee-flexion moment increased for the MPK compared to the NMPK (p=0.01) but remained significantly reduced compared to control subjects. The gait symmetry also increased for hip and ankle sagittal moments when using the MPK. This improvement in the stance phase knee moment is very important because the knee joint is the most important joint for the stability during stance. The heel strike and the loading response phases of the prosthetic limb are recognized as the most critical phases of an amputee’s gait [9]. The results suggest that the MPK improves amputee gait through more natural and smooth movements and could explain the improved balance and stability found in a previous study [10].

CONCLUSIONS
The results of this study indicate that a MPK has significant advantages over a NMPK for unilateral transfemoral amputees walking at self-selected speeds. One of these advantages includes enhanced gait symmetry in the sagittal plane. The results of this investigation not only highlight measured differences between the MPK and NMPK, but also offer a new method for assessing the gait symmetry. This type of analysis will be useful for clinicians to better detect gait impairments and to quantitatively monitor change in gait as a function of recovery.

REFERENCES